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ECONOMICS OF AGRICULTURAL POLLUTION CONTROL: A CONCEPTUAL ANALYSIS AND LITERATURE REVIEW*

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I. Introduction

Pollution is defined as introduction of materials into the environment that are potentially harmful or interfere with man's use of the environment. The contamination of soil, water, and the atmosphere by various substances are three types of special concern (Tver 1981, 252-253). The economic meaning of pollution is determined by physical and biological effects of pollutant discharges on scarce resources and by the loss of human welfare (Pearce and Turner 1990, 61-2).

The large increase in the use of agricultural chemicals in modern agricultural practices has contributed to increased food and fiber production. However, intensive use of agricultural chemicals generates pesticide and nutrient residues. These residues can adversely affect water quality when they reach surface or ground water in excessive amounts (Duttweiler and Nicholson 1983). in recent years, public concern over adverse effects of water pollution on both human health and environmental quality has been growing. This growing concern partly stems from widespread reports of agricultural pollutants in both surface and ground water.

Agricultural contaminants of major concern in surface water quality problems are soil particles, nutrients, and toxic chemicals including herbicides, insecticides, and fungicides. These materials reach nearby surface water carried by runoff water during rainfall, and contribute to three general forms of surface water pollution: (1) sedimentation; (2) nutrient enrichment by nitrogen and phosphorus;

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and, (3) contamination from toxic chemicals. Adverse impacts of sediment include damages to aquatic organisms, water-based recreation, navigation, increased flood damages, and raised water treatment cost. Nutrient enrichment adversely affects aquatic habitats, damage water-based recreation, and hampers water purification by stimulating algal growth. increased algal growth increases the cost of treating water for municipal and industrial uses. Furthermore, the combined effects of nutrient enrichment (eutrophication) in the stream can cause massive fish kills. The potential damage associated with a particular toxic pesticide depends upon its toxicity, solubility and persistence. Toxic chemicals in drinking water supplied by surface water may cause chronic effects such as cancer, miscarriage, and mutations (Libby and Boggess 1990).

Agricultural contaminants most likely to adversely affect ground water quality are pesticides and nitrates. Pesticides and nitrates, along with the percolating water after rainfall or irrigation, pass through the soil profile and below the crop root zone and may reach ground water. The potential for agrichemical leaching is largely determined by three categories of factors including (1) natural characteristics of the site of agrichemical use that affect leaching of water and thus transport of agrichemicals; (2) nature and extent of human modification to those natural characteristics that may affect leaching patterns; and, (3) characteristics of the agrichemicals (Office of Technology Assessment, 1990). Factors included in the first category are local topography and landforms, vegetation, climatic parameters, the depth to the water table, and soil characteristics. The second category includes tillage practices, the amount and the timing of agrichemical applications, and irrigation. Chemical characteristics include solubility, mobility, degradation, and adsorption (Office of Technology Assessment, 1990).

The purpose of this paper is to review the economic literature addressing important issues of agricultural pollution control. The second chapter of this paper develops the theoretical basis for a conceptual analysis of the problem at issue. The third chapter presents an overview of the literature on economics of agricultural pollution control. in the last section of this paper, future study needs in Korea are briefly discussed as concluding remarks.

II. Economics of Agricultural Pollution Control

1. An Overview of Agricultural Pollution Control Policy Alternatives

Policies for controlling pollution can be classified into two groups: (1) incentive policies which intend to improve water quality indirectly by providing economic incentives, including taxes or subsidies for polluters to reduce pollution, and (2) regulatory policies which force the farmer to comply with certain restrictions on the magnitude of pollutant emissions (emission standards) or polluting activities. in case of point source pollution, the use of incentive policies is more efficient than that of regulatory policies since the unit-tax approach can automatically produce the least-cost assignment of emission standards without the need for any complicated calculations by the regulatory agency (Baumol and Oates, 1975).

Pollution caused by agricultural chemicals poses special problems because (1) agricultural pollution is typically a result of generally accepted farm management practices, such as spreading fertilizers or applying pesticides according to label instructions; (2) most agricultural pollution sources are nonpoint sources making monitoring and testing procedures and their management difficult and expensive; (3) the pollution potential of agricultural chemicals and the effectiveness of control methods are site-specific; (4) there is strong resistance from agriculturalists to traditional approaches that force the polluter to bear the full cost of the polluting action; and, (5) the health and safety implications of ground water contaminations are uncertain (Batie et al., 1989). Because of the diffuse nature of discharges and the time lag between discharges and actual contamination of the water body, however, monitoring agricultural discharges is quite difficult and costly. Thus policy makers tend to rely on regulatory policies, such as agricultural input use restrictions or permits, to abate agricultural pollution. Particularly, regulatory policies are known to be more effective in protection of local environmental conditions than incentive policies (Anderson et al. 1990).

The magnitude of water pollution generated by agricultural production processes can be reduced by chemical input use reductions, input substitutions, crop rotations, and/or new technology adoption. Both incentive policies and regulatory policies would affect farm management practices, including tillage, chemical input usage, crop mix, and irrigation method which, in turn, would affect crop production and farm income. Thus, in choosing an agricultural pollution control policy option to be implemented, the economic implications of differing policy options, along with their estimated effects on water quality, should be considered. Comparing administration costs and practicality of differing options is also important. Considering these, four efficient policy options for agricultural pollution control are discussed in the following section. Each of these four policy options induces the least-cost rearrangement of production activities to comply with the given policy options. To implement these efficient policy options, detailed information on weather, chemical, hydrologic, and topographical characteristics of the farm land, and on the producer's practices for crop production, are required. The correct application of this information will provide estimates of effluent production from the farm. However, these efficient policy options inevitably involve high transaction costs due to the data requirements.

Some of the frequently mentioned pollution control policy options may have advantages of less transaction cost since they do not require detailed information. These policy options include taxes on nitrogen fertilizer and pesticides, restrictions on nitrogen use, taxes on irrigation water use, and restrictions on the amount of irrigation. These may be more acceptable policy options for addressing agricultural pollution problems when transaction cost of implementing policies are considered.

One of the most frequently mentioned control mechanisms to protect water quality is imposition of excise taxes on inputs that cause pollution. Imposing a tax on pollution-generating inputs is equivalent to forcing the marginal social cost of pollution to be reflected in the cost of input. The response of farmers to this control mechanism depends on the ratio of marginal value product to the price of input including tax. Thus, a substantial amount of tax may be required to induce a significant reduction in pollution-generating input use. The major advantage of an input tax would be the ease of implementation and relatively low administration cost. A drawback of the input tax policy is the difficulty in determining farmers' response in the input use to a given tax rate and its adverse economic impact on the farm sector. A low tax rate would not result in significant reductions in the use of polluting inputs. On the other hand, an excessively high tax rate would be met by strong opposition from the farm sector and agricultural chemical industry (Francis, 1992).

Other control mechanisms frequently mentioned are restrictions on agricultural input uses. An example of this control mechanism is restricting total nitrogen applications. This scenario represents a policy in which each farmer is granted a certain amount of nitrogen based on crop needs and in proportion to the number of acres of historic crop production. Additional information, such as soil type, residual soil nitrogen, or the availability of manure, could be used in determining the total nitrogen use. However, the farmer is free to allocate the nitrogen across crops and soils as he/she desires. One approach to implementing this policy would be to issue annual coupons or certificates to each farmer allowing the purchase of a given quantity of nitrogen fertilizer. Another example of this control mechanism is restricting total volume of irrigation water use. Using less irrigation water reduces chemical movements, especially chemical losses with deep percolation. This policy could induce a shift in irrigation technology from a less efficient system to a highly efficient one.

Pollution control policies that restrict the total amount of input use do not control the intensity of input use. The policy goal of reducing total input use does not address the problems of misuse and mismanagement. An alternative to the policy restricting the total amount of nitrogen application is a restriction on per acre nitrogen application. If high levels of nitrogen fertilizer use on certain crops cause unacceptable levels of pollution, then a policy restricting per acre nitrogen application could be more effective in abating pollution. A reasonable degree of compliance could be attained with strict penalties combined with random spot checks. To achieve an acceptable degree of compliance with lower enforcement costs, an approach that shifts the burden of proof of compliance to the producer could be used. A disadvantage of this policy option is that the administrative and enforcement costs would be higher than those with the policy restricting the total amount of nitrogen application (Francis, 1992).

2. Simplistic Illustrations of the Pollution Control Problem

The model in this section describes the nature of economics of pollution control problem in a quite simplistic way. Consider a firm which produces a primary product (y) using a single type of input (x) in a competitive market. The firm is assumed to attempt to maximize profit. Consider also that the production process generates a single type of effluent (z) as a joint product. The production functions for these joint products are represented by:

$$y = f(x) \tag{1}$$

$$z = g(x) \tag{2}$$

where f is assumed to be a twice continuously differentiable strictly concave function, while g is assumed to be a twice continuously differentiable strictly convex function. Assume that these production functions are known with certainty by the firm as well as the regulatory agency. For the sake of simplicity, assume also that the damage cost per unit of the effluent (c) is a constant and is known by the regulatory agency. Suppose there are no incentives or regulations for reducing effluent discharges, then the objective of the profit maximizing firm is:

$$\text{maximize}(x)\text{: } \pi(x) = pf(x) - rx \tag{3}$$

where p denotes the price of primary product, and r represents the price of input. Then the optimality condition for the profit maximizing firm is:

$$pf_x(x) = r \tag{4}$$

Equation (4) indicates that the firm needs to set the value of marginal product equal to the price of input.

Meanwhile, the objective of society can be described by:

$$\text{maximize}(x)\text{: } s(x) = pf(x) - rx - cg(x) \tag{5}$$

The optimality condition for society is:

$$pf_x(x) = r + cg_x(x) \tag{6}$$

Equation (6) indicates that the social optimum requires the value of marginal product be equal to the sum of the price of input and the marginal damage cost of the input at a certain input use level.

In this example, the price of input represents the firm's (private) marginal cost, while the marginal damage cost represents the social marginal cost. Let us assume that x* denotes the input use level at which the social optimum condition (6) is satisfied. Because the production function (1) is assumed to be strictly concave, the input level satisfying the optimality condition for the firm (4) would be greater than x*. In other words, if there are no incentives or regulations for reducing discharges, the firm would increase input use beyond the socially optimal level. This level of input use do not enter the firm's objective function. Therefore, it is necessary for society to formulate appropriate pollution control measures in order to attain the socially optimal level of input use. Four possible means of pollution control that can motivate the producer's optimal behavior, or that enforce optimal input use, are (1) an effluent tax; (2) an effluent standard; (3) an input tax; and, (4) an input use standard.

The first policy tool imposes a tax (t_z) per unit of effluent generated from the production process. The firm's new objective function under this tax policy is represented by:

$$\text{maximize}(x)\text{: } \pi(x) = pf(x) - rx - t_z g(x) \tag{7}$$

The optimality condition for the problem (7) is:

$$pf_x(x) = r + t_z g_x(x) \tag{8}$$

Equations (6) and (8) reveal that the effluent tax rate (t_z^*) needed to attain the social optimum equals the damage cost per unit of the effluent (c). In this context, the optimal effluent tax is equivalent to Pigouvian tax (Pearce and Turner, 1990, pp. 85-7).

The second policy tool sets an upper limit (z°) on the magnitude of the effluent the firm may generate without penalty. Under this effluent standard, the objective function of the firm is:

$$\begin{aligned}&\text{maximize}(x)\text{: } \pi(x) = pf(x) - rx\\ &\text{subject to: } z^\circ = g(x)\end{aligned} \tag{9}$$

The Lagrangian to the problem (9) is:

$$L(x; p,r,z) = pf(x) - rx + \mu\,[z^\circ - g(x)] \tag{10}$$

Optimality conditions for the problem are:

$$pf_x(x) = r + \mu g_x(x) \tag{11}$$

$$z^\circ = g(x) \tag{12}$$

Comparison of equations (6), (8), and (11) identifies the following relationships between choice variables and parameters:

$$z^* = g(x^*) \tag{13}$$

$$c = t_z^* = \mu(p,r,z^*) \tag{14}$$

Equation (13) indicates that the optimum effluent standard needs to be set at the same level as the magnitude of effluent generated by the socially optimal input use level x*. Equation (14) indicates that the optimal effluent tax t_z^* and the optimal standard z* are the dual of each other.

The third policy tool imposes a tax (t_x) on the level of input use. The objective function of the firm under the input tax scheme is:

$$\text{maximize}(x)\text{: } \pi(x) = pf(x) - (r + t_x)x \tag{15}$$

The optimality condition for problem (15) is:

$$pf_x(x) = r + t_x \qquad (16)$$

Equations (6) and (16) identify the optimal input tax rate (t_x*) as:

$$t_x^* = cg_x(x^*) \qquad (17)$$

Equation (17) indicates that the optimal input tax rate (t_x*) needs to be set at a level which equals the marginal damage cost of the input used at the optimal level x*.

The fourth policy tool sets an upper limit (x°) on input use. The objective function of the firm under the input use standard is:

$$\text{maximize}(x)\text{: } \pi(x) = pf(x) - rx$$
$$\text{subject to: } x = x^\circ \qquad (18)$$

The Lagrangian to the problem (18) is:

$$L(x; p,r,x^\circ) = pf(x) - rx + \lambda(x^\circ - x) \qquad (19)$$

Optimality conditions for the problem are:

$$pf_x(x) = r + \lambda \qquad (20)$$
$$x = x^\circ \qquad (21)$$

Comparison of equations (6), (16), and (20) reveals the following relationships between the Lagrangian multiplier λ and parameters:

$$cg_x(x^*) = t_x^* = \lambda(p,r,x^*) \qquad (22)$$

Equation (22) indicates that the optimal input standard should be set at x*, and that the optimal input tax and the optimal input use standard are the dual of each other. Optimality conditions for the firm and society, and optimal policy options are summarized in Table 1.

TABLE 1 Optimality Conditions and Optimal Policy Options to Correct the Externality Problem

Optimality Conditions

Problem of the Society
$pf_x(x) = r + cg_x(x)$

Problem of the firm
(1) Without Regulation: $pf_x(x) = r$
(2) With Effluent Tax: $pf_x(x) = r + t_z g_x(x)$
(3) With Effluent Standard: $g(x) = z^\circ$
(4) With input Tax: $pf_x(x) = r + t_x g_x(x)$
(5) With input Use Standard: $x = x^\circ$

Optimal Policy Options
(1) Optimal Effluent Tax: $t_z^* = c$
(2) Optimal Effluent Standard: $z^* = g(x^*)$
(3) Optimal input Tax: $t_x^* = cg_x(x)$
(4) Optimal input Use Standard: $x = x^*$

3. Efficiency and Distributional Implications of Policy Options

Economic analysis of alternative policies for controlling pollution must address efficiency and distributional implications of the policy options. As briefly stated in the previous section, economists have argued that economic incentives, such as taxes on effluent discharges or a subsidy for abatement of discharges, would lead to the least-cost achievement of certain environmental quality targets since these incentives do not deprive private decision makers of flexibility of choice (Kneese and Bower 1968; Baumol and Oates 1975; Braden, 1988). Meanwhile, Anderson et al. (1990) argue that the superiority of the price mechanism is less apparent with limited information or considerable transaction cost. Furthermore, Miltz et al. (1988) demonstrate that the uniform standard outperforms the uniform tax in controlling ambient pollution levels over a potentially wide range of parameter values. Subsidies are not a viable policy option for controlling nonpoint pollution since they are too costly and subject to perversion (Braden, 1988).

In the theoretical discussions of pollution control, it is often assumed that evaluation of environmental damages caused by pollution is possible. Freeman et al. (1973, 83) interpret damages of pollution as society's maximum willingness to pay to restore the environment to a unpolluted state. However, it is difficult to determine the monetary value of damages caused by pollution. on the other hand, a regulatory agency can set minimum standards or acceptable standards of environmental quality that must be met in order to achieve a reasonable quality of life. No data on costs or damages of certain pollution levels are required to set these standards. An example of these standards is upper limit on concentration of a certain pollutant in a waterway. To attain these standards through the price mechanism, the tax rates should be selected so as to achieve specific acceptable standards rather than attempting to base them on the unknown value of marginal damages (Baumol and Oates, 1971).

Consider a single firm that generates an effluent in the production process. The marginal abatement cost of effluent discharge for the firm is represented by MAC curve in Figure 1. Assume that the regulatory agency has determined z^* as an acceptable standard. Then the tax rate for achieving this standard is t^*, and the optimal tax rate t* is the dual of the acceptability standard z*. Hence, both the tax policy and the standard policy are efficient. However, these two policy options have quite different equity implications. Under the standard policy, total cost to the firm to comply with the standard is AZz*, and the cost of damages resulting from effluent discharges z* is internalized by the affected group in society. On the other hand, if the regulatory agency adopt the tax policy, then the firm should additionally pay Ot*Az* as an effluent tax. This tax is interpreted as the firm's compensation for the damages caused by effluent discharges z* (Anderson et al., 1990).

Both the tax policy and the standard policy provide an incentive to shift the marginal abatement cost curve from MAC down to MAC'. After the shift of the marginal abatement cost curve, the firm would reduce the level of discharges to z*' to save an amount of tax and abatement cost equal to the area AA'Z under the tax policy. Under the standard policy, the firm would maintain the level of discharges at z* since there is no additional incentive to reduce effluent discharges. If there is no need of further improvement in environmental quality, then the tax rate needs to be lowered from t* to t'.

Now consider two firms that have different marginal abatement costs: the marginal abatement cost curve of the first firm is represented by MAC_1, and that of the second firm is represented by MAC_2 in Figure 2. Assume that the regulatory agency has determined $2Z_m$ ($OZ_m + OZ_m$) to be the acceptable standard. In this case, the optimal tax rate t* for achieving the standard needs to be set at the level rendering Z_mZ_1 equals Z_2Z_m. Under the tax policy, the firm with MAC_1 bears abatement cost equal to the area A_1ZZ_1 and pays an amount equivalent to the area $Ot^*A_1Z_1$ as an effluent tax. On the other hand, the firm with MAC_2 bears abatement cost equal to the area A_2ZZ_2 and pays an amount equivalent to the area $Ot^*A_2Z_2$ as an effluent tax. Notice that a firm with lower marginal abatement cost pays less tax than a firm with higher marginal abatement cost. Under the standard policy, two differential standards are required for minimization of the total abatement cost: Z_1 for the first firm and Z_2 for the second firm. Notice that a firm with lower marginal abatement cost bears relatively heavier burden than a firm with higher marginal abatement cost under the standard policy.

FIGURE 1. Taxes versus Standards

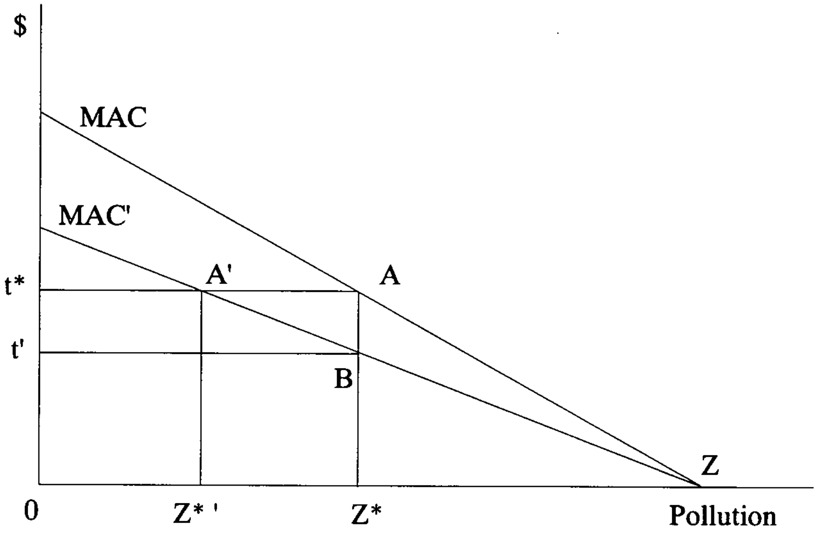
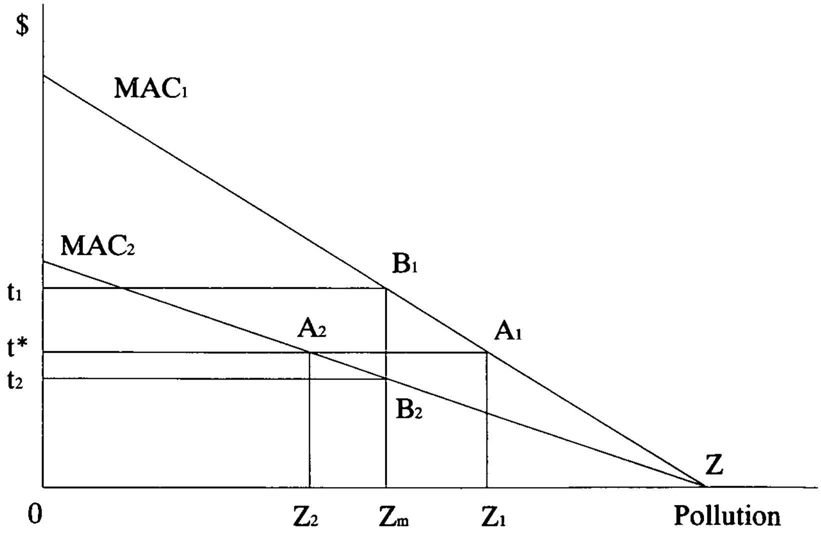


FIGURE 2. Differential Standards versus Uniform Standards



Previously discussed pollution control policy options do not consider either who is going to pay the costs for improving environmental quality or how much a group needs to pay. Under the tax policy, firms bear the burden of the effluent tax as well as the abatement cost. It may be questionable whether such an additional burden (tax) beyond abatement costs should be imposed on polluters. The tax revenue could be used to further improve in environmental quality or to compensate the affected group for loss of welfare. However, the main objective of imposing the effluent tax is to achieve the acceptable standard. In this context, the tax policy is considerably more disadvantageous to the affected firms than the standard policy. Furthermore, the economically efficient standard policy, which imposes a differential standard to each firm, emphasizes reducing discharges by firms with lower marginal abatement cost. Consequently, the differential standard policy heavily penalize firms with lower marginal abatement cost while allowing other firms with higher marginal abatement cost to continue their polluting activities.

To rectify this inequity, one may propose a uniform standard policy whereby all polluting firms are forced to reduce discharges by certain percentage of their original discharge levels. In case no regulations are imposed, both firms in Figure 2 would discharge an amount of effluent equal to Z, and so, bear neither tax nor the burden of abatement cost. Now, consider that the regulatory agency imposes the uniform standard Z_m on both firms. Notice that this uniform standard policy results in the same environmental quality with both the differential standards and the tax policy discussed above. The total amount of discharges from both firms is $2Z_m$. Under the uniform standard policy, the first firm bears abatement cost equivalent to the area B_1ZZ_m while the second firm bears abatement cost equivalent to the area B_2ZZ_m. Compared with results under the differential standard policy, the firm with higher marginal abatement cost bears greater abatement cost by an amount equivalent to the area $A_1B_1Z_mZ_1$. The firm with lower marginal abatement cost bears less abatement cost by an amount equivalent to the area $A_2B_2Z_mZ_2$. Consequently, the uniform standard policy involves a deadweight efficiency loss equivalent to the area $A_1B_1B_2$, although it contributes to the rectification of inequity problems.

III. Review of the Literature on Economics of Pollution Control

Baumol and Oates (1975, 18) define that "An externality is present whenever the decision maker, whose activity affects others' utility levels or enters their production functions, does not receive or pay in compensation for this activity an amount equal in value to the resulting (marginal) benefits or costs to others." Pollution is a good example of an externality for which polluters do not pay. In the absence of economic incentives to internalize the externality, firms release pollutants at a level higher than is socially optimal. For this reason, it has been conceived that taxes on the emission of pollutants, pollution generating inputs, or polluting activities, are necessary to motivate firms to economize on pollutant emissions. Plott (1966) shows that the tax to correct externalities should be placed on pollution generating inputs, and that it is impossible to attain optimality by placing a tax on the primary product.

Baumol and Oates (1975) provide an extensive conceptual discussion of externalities and the complexities of environmental policies. They assert that the quality of the environment depends on private, individual decisions and on collective action undertaken through the public sector because environmental quality is a public good consumed by all members of society. For this reason, they express doubts about the reliability of partial equilibrium analysis and provide a theoretical discussion of point source pollution problems utilizing general equilibrium models. Their analysis implies the standard Pigouvian result which requires a tax per unit of pollution generating activity equal to its marginal external damage.

Holterman (1976) discusses the use of taxes to correct externalities, and identifies three alternative methods of taxing externalities: (1) a tax placed on every unit of the externality produced; (2) a tax imposed only on the externality above a specified level; and, (3) a subsidy paid for every unit of the externality abatement below a specified level. Holterman (1976) concludes that Pareto optimality can be attained by imposing a set of taxes or subsidies on all inputs and outputs which contribute to the externality creation, even though it is not possible to impose taxes on externalities directly.

In a practical sense, it would be either impossible or too costly to determine consumers' valuations of marginal benefits of pollution abatement. For this reason, Griffin and Bromley (1982) develop a nonpoint externality theory by reformulating Baumol and Oates' general equilibrium models into a classical programming (optimization with equality constraints) framework. Assuming that a regional limit on pollutant emission discharges has been determined, and the objective is to achieve this goal at least cost to the region, they identify and model four types of policies regulating nonpoint-source pollution: (1) nonpoint incentives; (2) nonpoint standards; (3) management practice incentives; and, (4) management practice standards. Nonpoint incentives can be either a net charge or subsidy to each firm and depend on the incentive base level of pollutant emission. Management practice incentives also can be either a net charge or subsidy to each firm, and depend on the incentive base level of management practices. Nonpoint standards are the dual of nonpoint incentives, and management practice standards are the dual of management practice incentives in Griffin and Bromley's framework. Therefore, once the optimal levels of incentives are determined, the optimal standards can be obtained by applying Hotelling's lemma.

Griffin and Bromley (1982) consider just a single index of pollution since they implicitly assume that only a single pollutant is problematic in the region or that each pollutant is perfect substitute for other pollutants. This assumption has been adopted in many conceptual studies. Shortle (1984) explicitly assumes that there is only one agricultural pollutant. He concludes that the uncertainty regarding the magnitude of an agricultural pollutant would affect expected net benefits of alternative policy approaches and, therefore, should be considered when selecting appropriate pollution control policies. Shortle and Dunn (1986) incorporate the stochastic nature of runoff in their analysis and examine the relative expected efficiency of four general strategies proposed by Griffin and Bromley (1982). Assuming that farmers have better information about the effects of changes in farm management practices on profits, Shortle and Dunn (1986) suggest that appropriately specified management practice incentives would generally outperform the other three policy options regulating nonpoint-source pollution.

Many empirical studies have dealt with a single type of agricultural pollutant. Among others, Abrams and Barr (1974) consider surface water nitrate pollution in the State of Illinois. Horner

(1975) considers nitrate-nitrogen irrigation return flows in the western San Joaquin Valley. Jacobs and Casler (1979) consider phosphorus pollution of the Fall Creek watershed in central New York. Miller and Gill (1976) consider equity problem in controlling cropland sediment in Indiana. Wade and Heady (1977) examine effects of alternative policies to control sediment in the rivers and streams of the United States. Boggess et al. (1980) consider agricultural cropland sediment problem of a subbasin of the Iowa River in east central Iowa. Walker and Timmons (1980) consider agricultural cropland sediment problems in the Nishnabotna River Basin in southwestern Iowa. Segarra et al. (1985) conduct an analysis of soil erosion control on a representative farm in the Piedmont area of South-Central Virginia using a stochastic programming model. Gardener and Young (1988) consider salt discharges from irrigated crop land of the Grand Valley in western Colorado. Wu et al. (1989), and Braden et al. (1989) consider cropland sediment control problems in Illinois watersheds. Dinar et al. (1989), Knapp et al. (1990), and Caswell et al. (1990) consider quantity of drainage water for cotton production in the San Joaquin Valley of California. Bouzaher et al. (1990) discuss various mathematical models for efficient control of agricultural sediment and apply the models to examine effects of sediment control in Illinois. Johnson et al. (1991) consider nitrate ground water pollution problem caused by irrigated farms in the Columbia Basin of Oregon. Oh (1991) considers nitrate ground water pollution in western Franklin County and eastern Benton County in the State of Washington. Cole (1991) considers nitrate ground water pollution in Northwest Tennessee. Weinberg (1991) considers quantity of the agricultural drainage water for multiple crop production in California's San Joaquin Valley.

Only a few agricultural pollution control studies consider more than one kind of pollution load even though all types of agricultural pollutants deteriorate environmental quality or interfere with man's use of natural resources. Taylor and Frohberg (1977) examine welfare effects of alternative erosion control methods, banning pesticides, and limiting nitrogen fertilizer for reducing agricultural pollution in the Corn Belt. Pfeiffer and Whittlesey (1978) consider river nitrogen concentration, water temperature, and cropland soil losses in Washington State's Yakima River Basin. Braden et al. (1991) investigate the expected changes in farming practices and consequent losses in farming profit caused by control of soil erosion, sediment load, and pesticide losses in Lake Michigan tributaries. Richardson et al. (1991) attempt to quantify the impacts of a pesticide and inorganic nitrogen fertilizer bans on farming profits for representative farms in several southern States. Hoag et al. (1991) consider soil erosion, pesticide leaching, pesticide runoff, and excess nitrogen simultaneously, and assess the effects of alternative abatement targets on net returns to various cropping systems typical of the North Carolina Piedmont region. Taylor (1991) considers nitrate loss with percolation, nitrate and organic nitrogen loss with runoff, and assesses the required cost of complying with alternative control policy options to representative farms in Willamette Valley of Oregon. Taylor emphasizes that if only one type of pollutant is targeted for control, the other pollutants may be exacerbated. Teague et al. (1995) develop two environmental indices, one to indicate the level of environmental risk from pesticides and the other to indicate environmental risk from nitrates, and aggregated water quality effects across surface water and ground water. Using these indices, Teague et al. formulated a farm-level risk programming framework and applied it to a representative irrigated and dryland farm located in the Panhandle region of Oklahoma.

The equity of pollution control policies should also be addressed. As discussed in the previous section, an efficient pollution control policy from society's point of view does not consider who is going to pay the costs of improving environmental quality. An efficient policy only emphasizes pollution abatement by polluters with low marginal cost of the abatement. Thus, it could heavily penalize those with low costs of abatement, while letting the polluters with higher costs of abatement continue their effluent discharges unmodified (Kneese and Bower, 1968, 139-141). Political acceptability of such efficient policy options is highly questionable because of the expected strong resistance of the affected groups, and the perceived inequity of the redistribution of factor income. Sharp and Bromley (1979), and Park and Shabman (1982) provide additional discussions on these distributional issues.

Jacobs and Casler (1979) propose an alternative effluent tax policy which would preserve the benefits of the tax policy, yet not be excessively burdensome to farmers as polluters. Their approach is to identify the maximum allowable level of discharge and impose no tax up to this amount. This approach has exactly the same effects as the differential standard policy since no tax is actually collected. Thus every firm would comply with the differential standard. Consequently, this approach also imposes a heavier burden on firms with lower marginal abatement cost, as does the differential standard approach. Freeman et al. (1973. pp. 143-8) suggest the need to redistribute pollution control costs through direct subsidies or indirect cost subsidies such as favorable tax treatment for certain kinds of pollution control activities.

IV. Concluding Remarks

Agricultural production processes generate pollution, such as pesticide and nutrient residuals, which may contaminate both ground water and surface water. In recent years, public concern over possible adverse effects of water pollution on both human health and the environment has been growing. Historical policy prescriptions for improving water quality in the United States have focussed primarily on voluntary adoption of recommended crop management practices. But they have not been generally effective in attaining required water quality standards. It is important to formulate regulations and/or economic incentives that motivate farmers to make necessary changes for attaining reasonable water quality standards.

Agricultural pollution control measures imposing regulations or economic incentives aimed at protecting water quality will impact cropping alternatives, tillage practices, irrigation equipment and farm management decisions, technology adoption, and farm income. In Korea, few research have been conducted to assess the potential economic impacts of prospective policy alternatives which will modify agricultural and chemical use practices. Empirical studies that develop and apply analytical frameworks, which include both farm level and regional model linked with crop yield, farming practices, and chemical movements, are needed. Empirical analyses require agronomic, biochemical, and hydrologic information. Thus, it is quite important to develop biophysical simulation models that can represent both the characteristics of the agricultural pollution problem in Korea and the relationships between farming practices and environmental consequences.

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